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13. ABSTRACT

The Symposium on Biodynamics Models and Their Applications took place in Dayton, Ohio, on 26-28 October 1970 under the sponsorship of the National Academy of Sciences - National Research Council, Committee on Hearing, Bioacoustics, and Biomechanics; the National Aeronautics and Space Administration; and the Aerospace Medical Research Laboratory, Aerospace Medical Division, United States Air Force. Most technical areas discussed included application of biodynamic models for the establishment of environmental exposure limits, models for interpretation of animal, dummy, and operational experiments, mechanical characterization of living tissue and isolated organs, models to describe man's response to impact, blast, and acoustic energy, and performance in biodynamic environments.

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PAPER NO. 3

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SOME CURRENT BIOMECHANICAL RESEARCH IN THE UNITED KINGDOM, AS RELATED TO THE EFFECTS OF IMPACT AND VIBRATION ON MAN

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Although current research into models is not widely dispersed in the United Kingdom, models are used extensively as an aid to discussion.

Current research includes the dynamics of wrist movements, the use of a model for tractor seat testing, and the properties of body tissue. Work at the author's establishment is directed towards providing a range of information on the human dynamic response to impact and vibration. Studies range from transient and steady-state impedance experiments, to internal and external transmissibility measurements. It is suggested that a wider understanding of variations and non-linearities is required before useful analytic, and synthetic models can be evolved.

V

INTRODUCTION

The United Kingdom can lay claim to probably some of the earliest uses of models to explain man's response to shock and vibration. In 1957 Wing Commander Latham (1) used a single degree of freedom model to obtain a better understanding of the problems of pilot ejection. His work was, in fact, very advanced for the time, and he used one of the first analogue computers available in England. Unfortunately, since Latham's studies, there has been little published work on modelling in the United Kingdom. However, the importance of the shock and vibration environments is becoming increasingly apparent. Models are used extensively as an aid to discussion, but current research into models is not widely dispersed.

This paper will describe work relevant to this meeting which is being carried out at some institutions in the United Kingdom. However, other groups are also carrying out research into other aspects of the effect of shock and vibration on man. At Loughborough University of Technology, there is a considerable interest in modelling, and a large proportion of this paper deals with the Loughborough work. It is hoped that this does not indicate any undue bias on the part of the author.

THE UNIVERSITY OF STRATHCLYDE

The Bio-mechanics Unit at Strathclyde is the major research centre in the United Kingdom studying the mechanical properties of body tissue. Professor Kenedi will no doubt describe some of the activities of his unit in his paper tomorrow. However, one particular piece of work by Dr. J. B. Finlay (2) on the dynamic properties of skin is of interest. Dr. Finlay carried out skin torsion tests using a 15 m/m diameter disc rotating inside a 23 m/m inside diameter guard ring. The disc rotational movements were sinusoidal, and a servo system was used to ensure constant displacement amplitude. He found that from 0.004 Hz. to 1 Hz. a constant phase relationship existed, with torque leading displacement by 10^{o}. From 1 Hz. to 10 Hz. there was a noticeable rise in the phase curve, with a maximum lead of 15^{o} at 10 Hz. He found that this constant phase relationship occurred in both the low amplitude case (linear region) and the high amplitude case (non-linear region).

The skin is thus behaving thixotropically (as the synovial fluid, it contains a considerable proportion of long chain molecules). Finlay has pointed out that one should consider the possibility of rate dependent damping in models of the body.

Finlay's results are similar to those of Vlasblom. However, Vlasblom used a constant current driving system which has a constant torque characteristic at low frequencies, but not at high frequencies. Probably for this reason Vlasblom's phase changes at higher frequencies were greater than those obtained by Finlay.

THE UNIVERSITY OF EDINBURGH

Dr. Walsh of the Department of Physiology has for some time been interested in body movements during vibration. In a paper given at a recent informal meeting on human response to vibration (Reference 4), Dr. Walsh has described experimental studies of hand movement. General studies of the effects of vibration on tracking performance are made difficult by lack of knowledge of the movement of body parts. Dr. Walsh has attempted to study wrist movements, isolated from the effects of whole body vibration. He used a printed circuit motor to give flexion and extension at the wrist. The printed circuit motor affords a drive system which can be servo-controlled to provide constant torque. Dr. Walsh found that wrist displacement showed a resonance at about 5 Hz. The resonant frequency increased, or decreased as the wrist was stiffened or relaxed respectively. By using velocity feed-back, he was able to induce tremor at the resonant frequencies.

THE NATIONAL INSTITUTE OF AGRICULTURAL ENGINEERING

This Institute has long been concerned with the effects of vibration on tractor drivers. In order to assess the value of different anti-vibration seats for tractors, Tomlinson (5) has developed a dummy similar to that of Suggs (6) at Raleigh. The usual approach in this situation is to use impedance techniques to compare the dummy with man. However, Tomlinson is only interested in the value of the seat in attenuating the

tractor vibration, and methods of standardization of measurement of the attenuation. Consequently, Tomlinson rates the acceptability of his model in terms of the transmissibility of the seat using the dummy, compared with that occuring when a man sits on the seat. Tomlinson based his dummy on a Coermann type parallel two degree of freedom model, and then varied the parameters until seat transmissibility was similar to that when carrying a human. Tomlinson's final design had the following parameters:

First System: Mass - 13.1 Kg., Stiffness - 19.7 Kg/cm.
Damping factor - 0.35, Damped natural frequency - 7.2 Hz.

Second System: Mass - 24.9 Kg., Stiffness - 13.4 Kg/cm.
Damping factor - 0.30, Damped natural frequency - 3.8 Hz.

A rigid framework and fibre-glass seat moulding brought the total weight of the dummy to 57.3 Kg. The model is therefore equivalent to a 76 Kg. human, if one assumes 75% of body weight carried by the seat. Using different tractor seats, Tomlinson compared seat displacement transmissibility measures obtained for four subjects (of weights 65-75 Kg.) with those for the dummy. The results for a typical seat are shown in Fig. 1. Bearing in mind the range of variation between the subjects, the dummy is obviously useful as a means of simulating man in comparisons of seat transmissibility.

THE ROYAL AIRCRAFT ESTABLISHMENT

The Human Engineering Division of the Engineering Physics Department have underway a variety of research programmes dealing with human responses to shock and vibration. A single degree of freedom model concept has been used by J. Rayne (7) in considerations of flying helmet design. Rayne is considering the rotational movement obtainable from linear blows to explain concussion phenomena.

A warning to many research workers in the vibration field is evident in the work of Rowlands (8). He was faced with the need to carry out transmissibility measurements using a dynamic simulator which had extensive harmonic distortion in the acceleration waveform. Rowlands has taken into account the harmonic content at each frequency in order to obtain a better approximation to true sinusoidal transmissibility. Very few vibrators useful for human response studies have a true sinusoidal acceleration waveform and Rowlands' work indicates that one should at least consider the harmonic distortion present. He found that harmonics certainly affect the apparent transmissibility obtained. Non-linear systems can generate harmonics in the output regardless of the input, and Rowlands is considering the use of this phenomenon as a method of indicating non-linearities in the human system.

THE UNIVERSITY OF SURREY

Another disturbing fact for researchers in the modelling field arises from work by Mr. Hayden and Wing Commander McKenzie-Pratt (9) in the Mechanical Engineering Department at Surrey. They were attempting to model the human chest response to the type of blow received in a motor-car accident. Initially, they found that the static response of a cadaver chest was similar to that of the live human. However, under dynamic conditions the similarity no longer existed. They applied blows of about 160 m.sec. duration (sine pulses) to the chest of standing subjects. The tolerable force level was about 200 lbs. (4 to 5 times the static tolerance). However, when they applied the same impacts to fresh cadavers (supine in this case) over 50% of the ribs cracked.

The use of cadavers for injury simulations would obviously be wrong in these studies. Bearing in mind the expected similarity between actual bone strength of the cadavers and live subjects, the results suggest that the mechanical responses of the chest are completely different. One would, of course, expect differences due to muscle tone and thorax pressure, but the degree of difference demonstrated should give a severe warning against neglect of these factors. The experimenters are now designing more sophisticated equipment so that the mechanical responses of the human chest can be studied more fully.

LOUGHBOROUGH UNIVERSITY OF TECHNOLOGY

In the Department of Ergonomics and Cybernetics there is a strong interest in the effects of shock and vibration on man, with the present research programme centred on investigations into the mechanical responses. However, before considering this work in detail, another piece of work carried out in the Department is of interest.

Mitchelson (10) is concerned generally with the possibility of using upper arm movements to control a lower arm prosthesis, and this preliminary study was to investigate the relationships between upper and lower arm movements. The subject was asked to move a stylus between two points on a board placed horizontal, at 45°, and vertical. Thus, the upper arm had the same total angular movement, but followed different time/displacement patterns. The movements were filmed and the arm co-ordinates obtained from each frame of film.

Mitchelson found that the initial angular velocity of the upper arm movement was least for the vertical hand motion and greatest for the horizontal hand motion. He considers that his results generally support the possibility of the existence of unique relationships between upper and lower arm movements, and therefore the possibility of prosthetic control. Equipment is now being designed that will give direct electrical signals indicative of the arm positions. This will eliminate the time consuming scanning of the cine film required at the moment.

This work is mentioned not so much for its immediate interest, as for the possibilities it introduces for research into the effects of vibration on manual control.

The work of the bio-dynamics group is centred on the need for a better understanding of the responses to the mechanical environment. Studies range from the long and short duration impact situation to the vibration situation.

The Department is under contract to the Ministry of Technology to study the mechanical responses of man during impact with the aim of providing parameters for the design of a dummy to be used in ejection seat testing.

During the development of the investigation, it soon became clear that initially, it would be necessary to restrict the study to the first part of the ejection sequence, when the direction of impact is approximately parellel to the spine.

The need to provide parameters for a piece of hardware leads to important considerations. The high initial cost of a dummy, and the large number likely to be damaged in testing, result in the need for only a simplified representation - two or three degrees of freedom at the most. If the dummy is to be representative of the aircrew population, then it must be capable of taking into account the variation in mechanical response likely to occur. In general, one would expect these two requirements to be mutually opposed, and in consequence a great deal of emphasis has been placed on gaining an understanding of the variations in response over the population concerned.

In order to provide some form of reference where variations are likely to be least, the experiments are initially quite consciously restricted. The subject sits directly on a hard-faced measuring cell with no restraint, so that seat and restraint dynamics are eliminated. Normally the subject is asked to sit erect (at present he is assisted by a free-moving vertical support, and in the future attempts will be made to use electromyographic techniques to standardize posture), although he is also asked to slump slightly so that indications are obtained of the effects of postural change.

The experiments are restricted to low impact levels, so that large numbers of subjects can be used in safety.

Simple anthropometric measurements are taken, and the numbers of subjects will be sufficient to satisfy statistical testing of the hypothesis that variations in response are due to differences in body build.

Measurements are taken of the transient force and acceleration at the buttock-seat interface. The measurements are used to calculate the input mechanical impedance of the human system, and these measures are in turn used to propose analogue equivalents of the human system.

The subject is seated on a table which can fall freely for 2 metres onto a braking system using nylon tear webbing. An ejection seat may be fitted to the table if required. The table runs on two vertical guides, and is fitted with brakes sufficient to hold the table after its first

rebound from the braking system. To make better simulation feasible if required, the complete apparatus is operable at an angle to the vertical (maximum 30°).

The braking system consists of several strips of "ply-tear webbing" hung across the path of the table (thus cradling it as it falls). This braking system enables a trapezoidal waveform to be synthesized, although the waveform is rather noisy. The acceleration pulse of Fig. 2 shows a typical waveform. The pulse is, in fact, very similar to measured ejection seat accelerations. The equipment is illustrated in Fig. 3.

At the time of writing, insufficient results are available to enable any firm statements to be made about human responses. However, there are sufficient results to indicate the viability of the system. Figures 4a and 4b shows typical modulus, and phase-angle values obtained from four impacts using cast-iron weights totalling 80 Kg. The results indicate satisfactory performance up to about 30 Hz.

Figures 5a and 5b were obtained from five runs with a well built male subject sitting erect. The acceleration level was about 6 g. The impedance spectra are reasonably repeatable, and indicate series resonances at 5 to 6 Hz., and 9 to 10 Hz. However, only the 9 to 10 Hz. resonance is verified by the phase-angle plot. This resonance is in agreement with other authors (Yeager (11) and Wittman (12)). At lower acceleration levels (3 g.) the slight variation at 4 Hz. becomes more apparent. However, contrary to expectations, there is little change in the spectrum when the posture is changed.

Although the scatter is great, the modulus of impedance tends to increase with frequency above 30 Hz. (i.e. 'mass-like' response). This is not expected in simple systems, and has previously been observed by Weis (13). He considered that the effect may be due to restraint artifacts or non-linearities in the human system. The Loughborough equipment eliminates restraint effects, and one is faced with the possibility of non-linearities in the system.

A large number of subjects are being tested in a variety of situations, (long duration, low acceleration and short duration, high acceleration) and this should lead to a clear picture of human response before postulating the responses under the more severe conditions of pilot ejection. In another series of tests, Coermann's vibratory impedance experiments are being repeated. There are surprisingly few reports of large scale vibratory impedance studies. Using improved techniques, it is intended that large numbers of subjects, in a variety of postures will be measured.

This range of experiments varying from short duration impact to vibration, should enable conclusions to be drawn on the degree of non-linearity to be expected, variations in response due to posture, subject anthropometry, etc. With this basic information, more complex experiments necessitating small numbers of subjects can be considered with greater confidence in the results.

It is recognised that impedance techniques are valid only if the system is linear, and even then do not give all the information necessary for complex models (see Payne, 14). However, until methods of measurement of body movement are more accurate, the techniques give a basic datum for considerations of possible non-linearities, and model configurations.

At Loughborough we are anxious to know as much as possible about the transmission of mechanical energy through the body. Included in the experimental programme are such measurements as external transmissibility, internal transmissibility (e.g. intra-abdominal pressure), and muscle tone, so that more can be learnt of the human responses to impact and vibration.

CONCLUSIONS

The ultimate aim of modelling is surely the development of analytic models (from response studies) which are related to the descriptive models one would expect from a knowledge of the human anatomy and physiological responses.

If this aim is to be attained, then more knowledge is required of the propogation of forces through the body and body parts, the non-linearities to be expected in the human system, and the range of variations to be expected due to posture, subject anthropometry, etc. Although the work in the United Kingdom is widely varied, it is probably a good indication of the range of studies necessary for the evolution of useful models.

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ILLUSTRATIONS

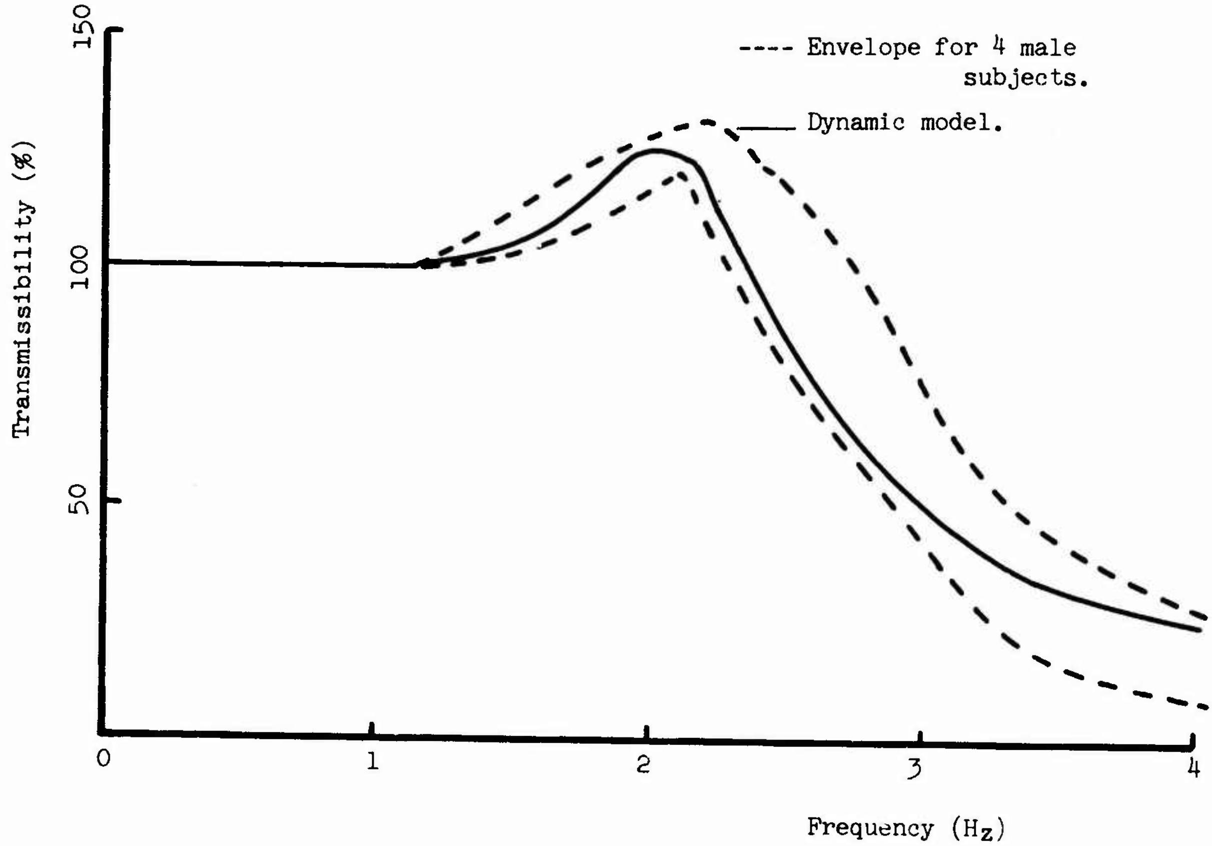

Fig. 1. Comparison of displacement transmissibility of dynamic model and male subjects.

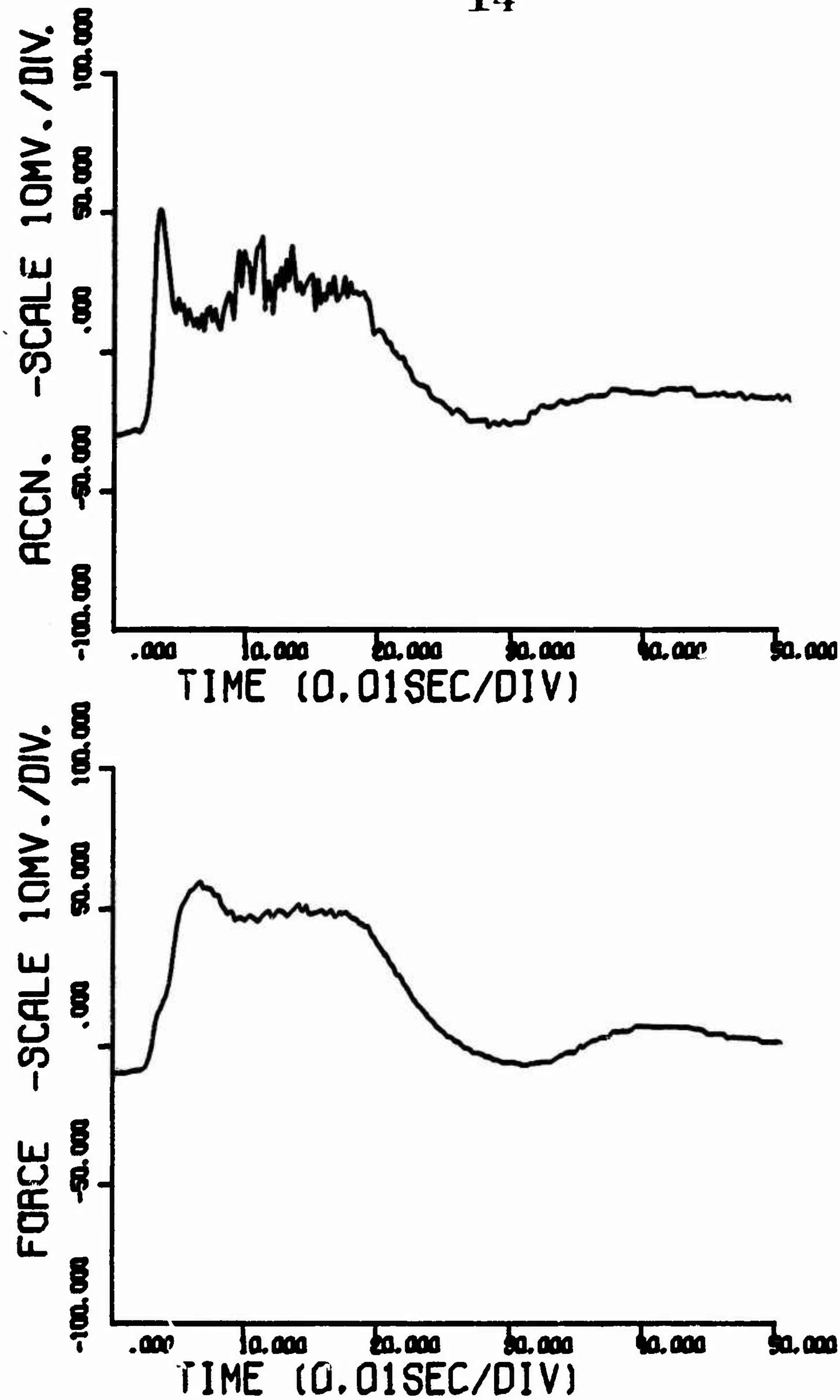

Fig. 2. Acceleration and force transients for 62.3 Kg. human, sitting slightly slumped, 60 m/sec.^{2}.

Figure 3: Subject seated on table

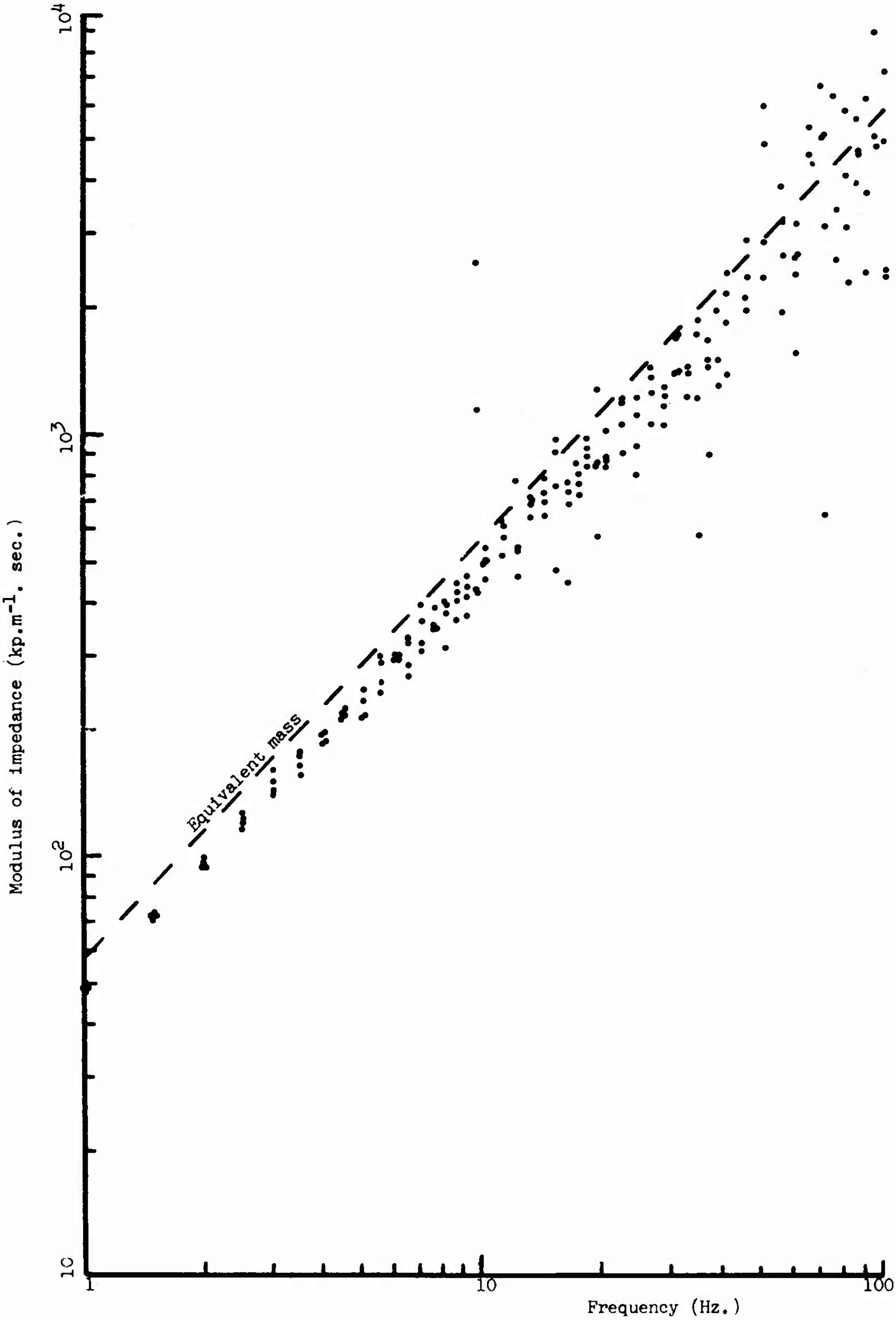

Fig. 4a. Modulus of impedance of 80 Kg. weight (data from four consecutive runs).

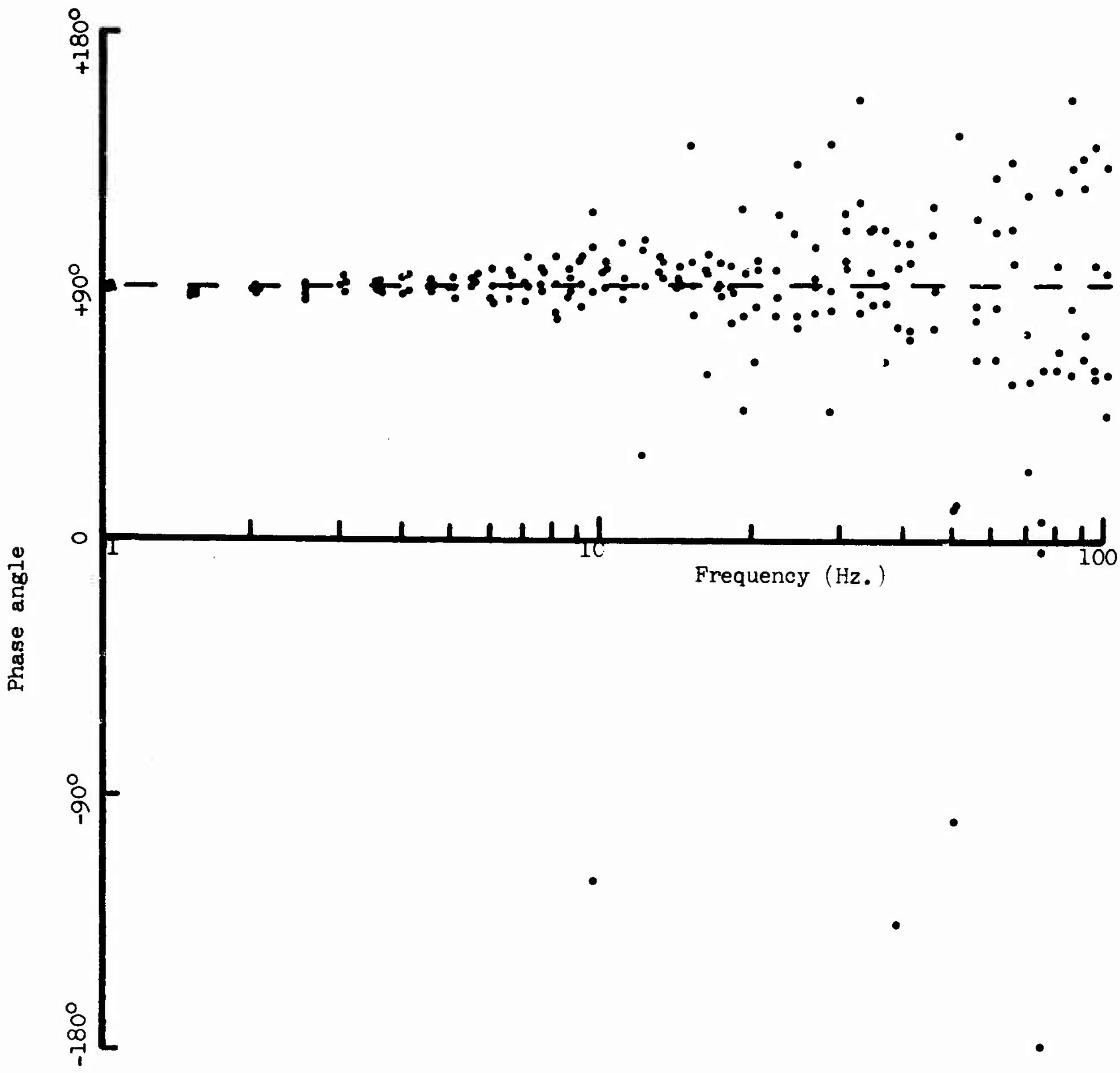

Fig. 4b. Phase angle of impedance of 80 Kg. weight (data from four consecutive runs).

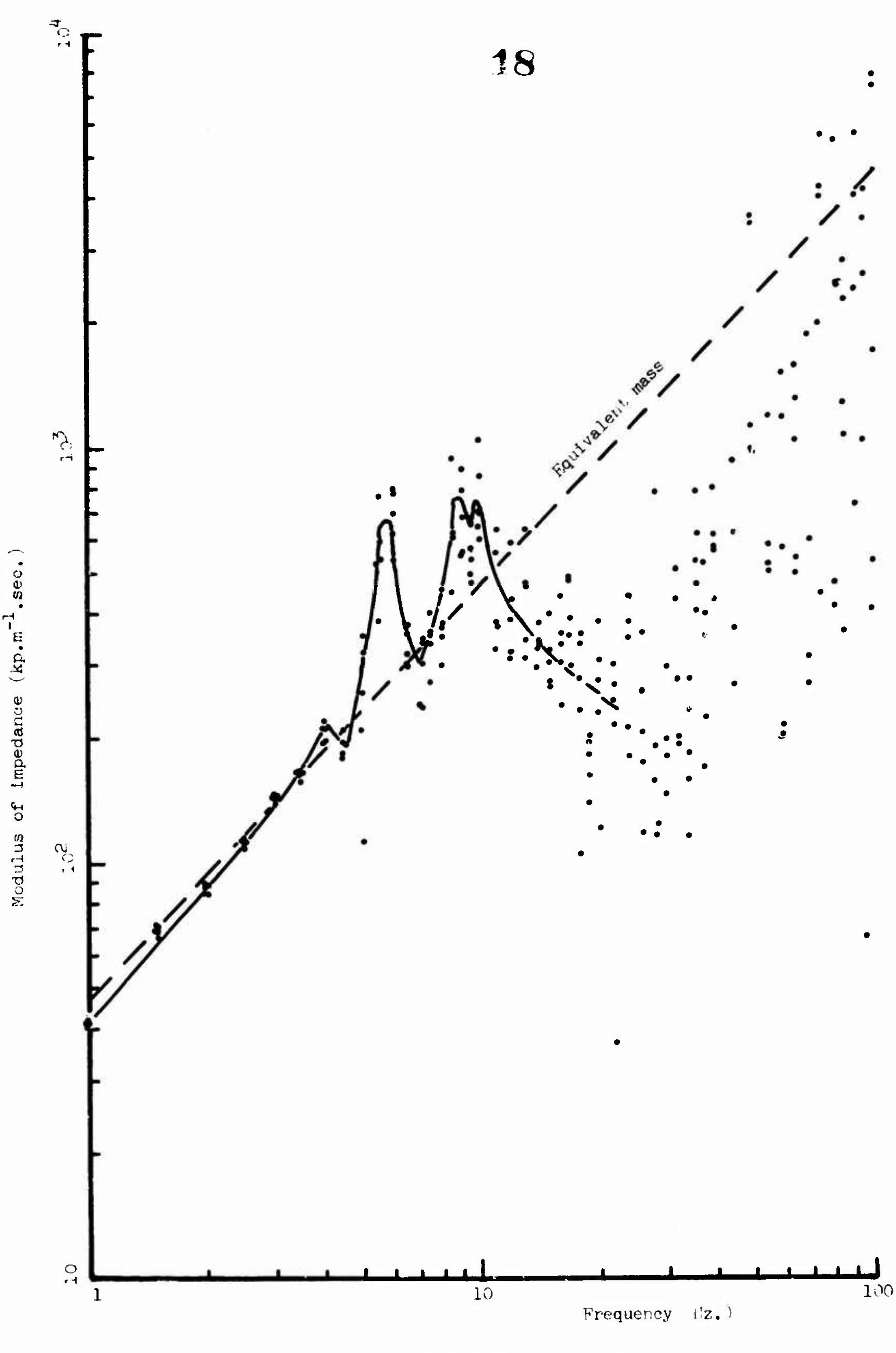

Fig. 5a. Modulus of impedance of 62.3 Kg. human, sitting erect, 60 m/sec.^{2} (data from five consecutive runs).

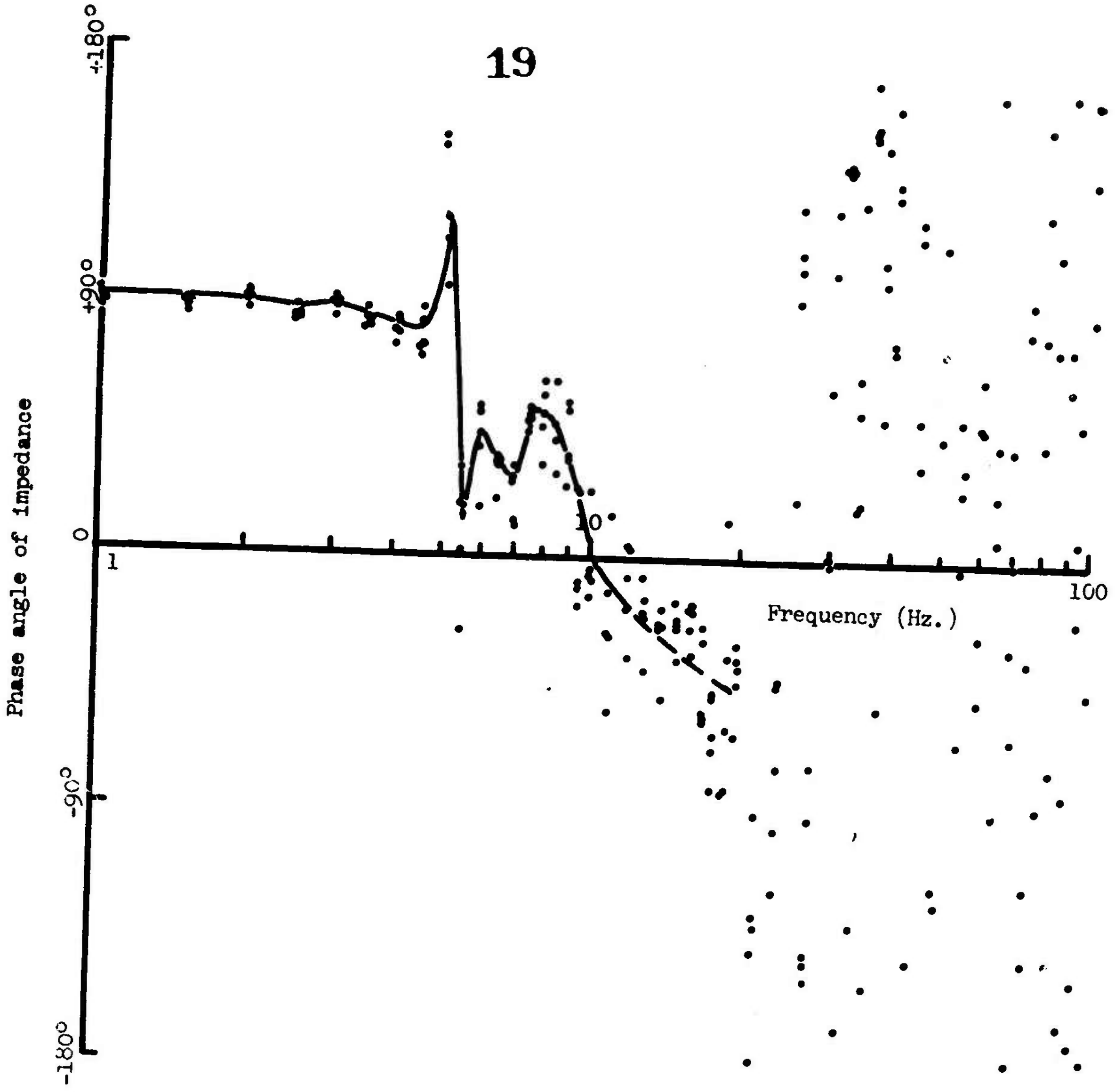

Fig. 5b. Phase angle of impedance of 62.3 Kg. human, sitting erect, 60 m/sec.^{2} (data from five consecutive runs).